- Today, more than half of the electricity generated in the United States comes from domestic coal reserves. Worldwide, coal fuels more than a third of electricity production. Even with maximum attention to energy conservation and increased use of renewable energy and natural gas, coal must continue to supply over half the nation's and over a third of the world's power needs well into the 21st century.
- A new generation of coal-based power systems is required to provide the energy to sustain economic growth domestically and internationally, while addressing global and regional environmental concerns.
  - SO_2 and NO_x emission levels become capped in the U.S. and subjected to increasingly stringent regulations abroad;
  - Particulate matter in the inhalable and respirable ranges ceases to be tolerated worldwide;
  - Vapor phase mercury emissions will be subject to control; and
  - Perhaps most importantly, global climate change concerns place a premium on efficiency to reduce one of the greenhouse gases, carbon dioxide (CO_2).
- Nearly half of the world's energy growth is seen to occur in coal-dependent developing Asia, primarily China and India. Advanced coal-based power generation systems are needed to prevent staggering growth in global greenhouse gas emissions and to comply with increasingly stringent pollutant standards.
- Domestically, energy forecasts suggest that new coal-fired baseload capacity will be required no later than 2005.
- In response to these needs, the CCT Program is demonstrating technologies that are not only redefining the state-of-the-technology in electric power generation but also are providing the building blocks for achieving:
  - Low-cost production of electricity, process heat, and high-value fuels and chemicals from a multiplicity of feedstocks (e.g., coal, biomass, and wastes);
  - Virtually no pollutant emissions; and
  - Efficiencies greater than 60 percent.
- In the 1970s, such power plants existed only as the hopes of researchers. Today, due largely to the CCT Program, these clean, highly efficient technologies are a reality, with further enhancements and advances on the horizon.

"We view our Clean Coal Technology project as a natural solution. Our customers will benefit from a reliable, economical fuel. Our environment will benefit from superior emissions reduction performance. And our company will benefit by producing reliable generation in a way that more than meets the Clean Air Act."
Girard F. Anderson
President, Tampa Electric Company

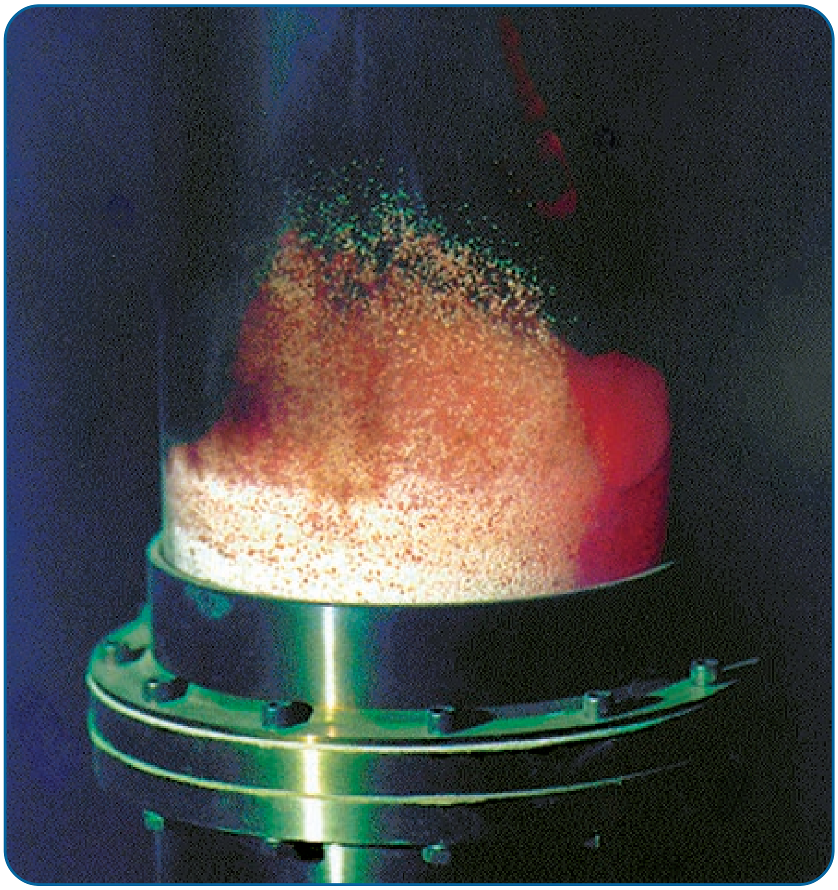
Fluidized-Bed Combustion

"Power" magazine called the development of fluidized-bed coal combustion "the commercial success story of the last decade in the power generation business." This success, perhaps the most significant advance in coal-fired boiler technology in more than half a century, resulted largely from research, development, and demonstration sponsored by the Department of Energy and its predecessors.

The CCT Program has been instrumental in providing the operating experience essential to commercial acceptance of fluidized-bed combustion for utility applications. The program's portfolio includes five fluidized-bed combustion demonstrations: two using atmospheric systems, and three using pressurized systems.

Fluidized-bed combustion reduces SO_2 and NO_x emissions by controlling combustion parameters and by injecting a sorbent (such as crushed limestone) into the combustion chamber along with the coal. The mixing action of the fluidized-bed, induced by jets of air, promotes efficient, homogeneous combustion and effective sorbent contact with SO_2. This enables efficient combustion at temperatures about half that of a conventional boiler, and below the temperature at which thermally induced NO_x is formed. Resultant SO_2 and NO_x emissions are quite low. The waste is a dry, benign solid that can be disposed of easily or used in agricultural or construction applications. Furthermore, the nature of fluidized-bed combustion makes it highly fuel-flexible.

Fluidized-bed combustion can be atmospheric or pressurized. Pressurized boilers operate at 6-16 times the pressure of atmospheric systems. Pressurized units offer potentially higher efficiency and, consequently, reduce operating costs and waste relative to atmospheric units.



Fluidized-bed research vessel used to study bed material movement

Atmospheric Fluidized-Bed Combustion

The Tri-State Generation and Transmission Association, Inc. demonstration of a 110-MWe atmospheric circulating fluidized-bed (ACFB) at Nucla Station, Nucla, Colorado precipitated commercialization of the technology. When constructed in 1988, the unit was 40 percent larger than any other ACFB at the time.

In a cooperative effort between DOE, the host utility, EPRI, and a Technical Advisory Group comprising interested utilities, the 110-MWe unit underwent an extensive test program to evaluate performance. The resultant comprehensive database and operating experience provided sufficient foundation for the technology supplier, Foster Wheeler, to offer the technology commercially at utility scale.

Today, all major boiler manufacturers offer an ACFB in their product lines. Since the demonstration, commercial sales of 29 units greater than 100 MWe have been realized, representing 6.2 gigawatts of capacity and nearly $6 billion.

A second demonstration project, located in Jacksonville, Florida, will carry on where Nucla left off. It will have the distinction of being the largest ACFB combustor in the world as well as one of the cleanest. At nearly 300 megawatts, the Jacksonville project will more than double the size of the Colorado unit.

During 15,700 hours of operational demonstration, Nucla achieved up to 95 percent SO_2 removal and averaged NO_x emissions of a very low 0.18 lb/10^6 Btu. The demonstration also resulted in the most comprehensive database on ACFB technology available to date. Using this knowledge, vendors were able to offer and build additional utility-scale units for commercial applications.

Nucla Station

Pressurized Fluidized-Bed Combustion

The attractiveness of PFBC technology lies in the benefits derived by pressurizing combustion to about 175 psi. Pressure enhances combustion efficiency and heat transfer, which permits use of a small, compact unit. High-pressure gas exiting the boiler drives a gas turbine and waste heat contributes to steam generation in a combined-cycle mode, providing a significant efficiency advantage. The Tidd unit shown here achieved greater than 95 percent SO_2 capture and NO_x emissions well within air quality limits without add-on pollution controls.

The nation's first large-scale PFBC power plant began operating in December 1990 at American Electric Power's (AEP) Tidd Plant in Brilliant, Ohio. The 70-MWe Tidd Plant used ABB Carbon P200 bubbling bed technology (licensed to Babcock and Wilcox).

AEP, one of the nations largest utilities, invested four years to fully test and evaluate the technology. Numerous design improvements resulted as AEP worked through a series of challenges that compromised performance. After 49 months of coal-fired operation and 95 individual tests, the Tidd project met its objective—the performance potential of PFBC was established and the foundation for commercialization was laid.

The success of the project has led Babcock and Wilcox, a major domestic boiler manufacturer, to invest in the technology and acquire domestic licensing rights. The technology is experiencing commercial success abroad as shown below:

- Vartan in Sweden is operating two P200 units to produce 135 MWe and 224 MWt.
- Escatron in Spain is operating one P200 unit to produce 80 MWe.
- Wakamatsu in Japan is operating one P200 unit to produce 71 MWe.
- Cottbus in Germany is operating one P200 unit to produce 71 MWe and 40 MWt.
- Karita in Japan will begin this year to operate one P800 unit to produce 360 MWe.
- Other projects under consideration are in China, South Korea, UK, and Israel.

Work has begun under the CCT Program to demonstrate a second generation PFBC at Lakeland Electric's McIntosh plant, using a Foster Wheeler circulating fluidized-bed system. The 240-MWe second generation system incorporates a carbonizer (pyrolysis unit) to produce synthesis gas for combustion in the gas turbine (solid product goes to the combustor). The additional energy developed in the more efficient gas turbine significantly enhances efficiency— 45 to 50 percent depending on the gas turbine used.

Tidd 70-MWe PFBC

Integrated Gasification Combined-Cycle

Four integrated gasification combined-cycle (IGCC) projects in the CCT Program will demonstrate a full range of variations of the IGCC process: different gasifiers, different sizes, different coals, different cleanup systems, and different applications (greenfield and repowering).

Tampa Electric Company, as part of a major expansion over the next decade, has built a 250-MWe IGCC facility as a greenfield plant in Florida. Polk Power Station, Unit 1, began commercial operation in September 1996. Since then, the unit has logged over 15,000 hours and produced over 3,500,000 MWh of electricity on syngas.

The project couples Texaco's oxygen-blown, entrained-flow pressurized coal gasifier to a power island consisting of both a combustion turbine and a steam turbine. The project also incorporates an innovative hot-gas-cleanup system to boost efficiencies even further. The plant uses high-sulfur coals.

Worldwide commercialization of IGCC has already begun. General Electric has identified 21 IGCC projects (11 installed and 10 moving forward), representing approximately 5.1 gigawatts of capacity. Unit sizes range from 40 MW to 550 MW and include a variety of fuels, 10 different gasifiers and a variety of applications. Ten of the projects use Texaco gasifiers. Furthermore, Texaco and ASEA Brown Boveri have formed an alliance to market the Texaco IGCC technology in Europe.

Polk Power Station is the first greenfield IGCC unit in commercial operation. In achieving this accomplishment, both the environmental and technical community bestowed accolades on Tampa Electric. The site was chosen through formal environmental consensus, cleaning up an abandoned phosphate-mined area and expanding wetlands in the process. For its technical efforts, the Polk Power Station received *Power* magazine's 1997 Powerplant Award. The utility's contributions to the innovative siting process garnered the 1993 Ecological Society of America Corporate Award, the 1993 Timer Powers Conflict Resolution Award presented by the state of Florida, and the 1991 Florida Audubon Society Corporate Award.

Integrated gasification combined-cycle (IGCC) systems offer another clean, highly efficient means of power generation. IGCC converts coal into a gaseous fuel, which lends itself to pollutant removal. The clean fuel gas is then combusted in a gas turbine to generate electricity. Excess heat is put to work in a conventional steam turbine generator, producing even more electricity.

Typically, more than 99 percent of the sulfur pollutants are captured and converted into sulfuric acid or elemental sulfur, both salable by-products. Nitrogen oxide emissions are about one-tenth those of a conventional power plant. Any trace elements in the coal stay with the ash, which is either converted to an inert glass-like slag or a dry solid with cement-like properties.

Polk Power Station 250-MWe IGCC facility

Wabash River Coal Gasification Repowering Project Joint Venture repowered one of six units at CINergy's Wabash River Generating Station in West Terre Haute, Indiana. The demonstration unit generates 262 MWe using an IGCC system, making it the world's largest single-train IGCC plant currently in operation.

The project demonstrates Dynegy's two-stage, oxygen-blown, entrained flow pressurized coal gasifier, which produces a medium-Btu syngas from high-sulfur coal. The technology boosted the efficiency of the repowered unit by about 20 percent, decreasing CO_2 emissions by a comparable percentage. Emissions of SO_2 and NO_x are well within compliance requirements and the solid by-product (a glassy inert slag) has value as an abrasive or construction material.

The unit began operations in December 1995 and went into commercial service. CINergy preferentially dispatches the unit second behind its hydroelectric facilities on the basis of environmental performance and efficiency.

Since beginning operation in 1995, the Wabash River Generating Station 262-MWe IGCC unit has operated on coal for over 12,400 hours and processed more than one million tons of coal. The unit has achieved monthly production levels of one trillion Btus of syngas on several occasions. *Power* magazine presented the Wabash River project the 1996 Powerplant Award. That same year, Sargent & Lundy won the American Consulting Engineers Council Excellence Award for their efforts on the Wabash River project.

Wabash River Generating Station 262-MWe IGCC

Sierra Pacific Power Company's 99-MWe IGCC

Sierra Pacific Power Company hosts the latest IGCC demonstration at its Tracy Station near Reno, Nevada. The 99-MWe (net) unit uses KRW's air-blown pressurized fluidized-bed gasifier and hot-gas-cleanup to produce low-Btu syngas.

Sierra Pacific Power Company completed construction in early 1995 and began start-up efforts in mid-1996. The General Electric combustion turbine at the unit is the first of its kind in the world and was successfully fired for the first time in August 1996 using natural gas. The combined-cycle part of the plant began commercial operation on natural gas in November 1996. Operational testing will continue through July 2000.

Efforts continue to increase the hours of gasifier operation. A key feature of the project is the use of fluidized-bed gasification, which affords tremendous fuel flexibility. In approving the project, the Public Service Commission of Nevada cited the technology's advantages of "flexibility, diversity, and reliability." Low-sulfur western coal will be used in the plant as the baseline fuel, although high-sulfur eastern coals also will be tested.

Clean Energy Partners Limited Partnership, the fourth IGCC project, will demonstrate a British Gas/Lurgi slagging fixed-bed gasification system coupled with Fuel Cell Engineering's molten carbonate fuel cell. Conventionally cleaned medium-Btu fuel gas fires the gas turbine in the IGCC power island. A small portion of the hydrogen-rich clean gas fuels the fuel cell.

Advanced Combustion Technologies

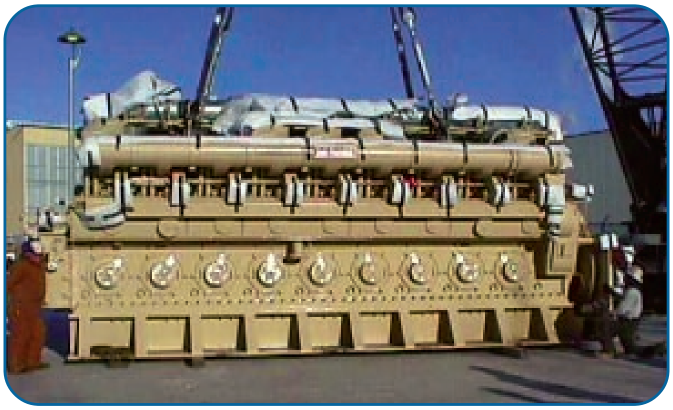
The Alaska Industrial Development and Export Authority is sponsoring a demonstration of TRW's advanced slagging combustor in a 50-MWe unit near Healy, Alaska. Power is purchased by Golden Valley Electric Association (GVEA).

Healy Generating Station

The combustors stage combustion to minimize NO_x emissions. Low SO_2 emissions result from limestone injection into the combustor and coupling the combustor with a dry scrubber. The demonstration unit operates on 35 percent run-of-mine coal and 65 percent waste coal. High combustion temperatures convert ash to a salable inert, glass-like slag.

Start-up of the TRW entrained slagging combustion system began in January 1998 and results show very low NO_x and SO_2 emissions, 0.25 lb/10^6 Btu and 0.8 lb/10^6 Btu, respectively (below permitted levels). Almost all of the ash is being converted to slag before entering the furnace. To address concerns about potential impact to the nearby Denali Park and Preserve, DOE, GVEA, the National Park Service, and the project sponsor took action to reduce emissions from the existing coal-fired unit. TRW is offering licensing of its technology worldwide and already has a licensing agreement in place in China.

Arthur D. Little, Inc., plans to demonstrate a 6.4-MWe Coltec coal-fired diesel engine at the University of Alaska in Fairbanks. The university also will assemble and operate a coal-water fuel-processing plant that will utilize local low-rank coal. The coal-water fuel also serves as an alternative to fuel oil in conventional oil-fired industrial boilers.



Coltec coal-fired diesel engine

The Coltec engine is best suited for dispersed power applications in the 5–20 MWe range. The high overall system efficiency (41-48 percent) and very low pollutant emissions make it very competitive with similarly sized fuel-oil-fired and coal-fired systems. The U.S. diesel market is expected to exceed 60 gigawatts through 2020 alone. The market in developing Asia for coal-based distributed power is far greater.